Devolatilization of Carbonate-Rich and Carbonaceous Rocks as Fluid Source for the Outokumpu Cu-Zn-Co-Ni-Ag-Au Deposit, Eastern Finland

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Ultramafic-hosted VMS deposits have been systematically overlooked. Reasonably, textural overprint by deformation and high-grade metamorphism conceal the origin of the ore. Such case is the polygenetic Outokumpu Cu-Zn-Co-Ni-Ag-Au deposit. Samples retrieved from the Outokumpu Deep Drill Hole, which crosscuts the Outokumpu ophiolitic complex, and former mines (Vuonos, Kotalahti) are studied. The ophiolite contains the homonymous assemblage, i.e., ultramafic rocks, calc-silicate rock (diopside-tremolite skarn), and quartz-rock, enclosed within a thin black schist envelope as m- to km-scale lenses. Petrographic relationships, µ-XRF, sulfide and oxide EPMA and LA-ICP-MS, and thermodynamic modeling are utilized. Devolatilization of the diopside-tremolite skarn and the black schist during prograde metamorphism mobilized S and the critical elements Co, Ni, Bi, Te, and Sn that subsequently precipitated in the form of sulfides in the ultramafic rocks. Devolatilization is additionally indicated by molybdenite flakes in graphite-rich portions of altered rock and elevated Ga-contents of Cr-V-Ti-Al-Zn-poor metamorphic magnetite. Initial thermodynamic calculations show >20 and >25 mol% H_2O and CO_2, respectively, at 300°C, with dissolved H_2S as the mobilizing fluid.

Nickel contents in pyrrhotite are different from pyrrhotite in orthomagmatic deposits (10-100 times less Ni) but have similar Ni-Co concentration ranges (~0.01-0.50 wt.%) and Co/Ni-ratios (~0.02-3) to ultramafic-hosted deposits (Troodos, Cyprus). Additionally, Bi, Pb, Sn, and Te have high concentrations in the whole ore mineral range (up to ~0.1-0.2 wt.% for each element), dissimilar from ultramafic-hosted VMS deposits. These features support the hypothesis that the proto-ore originated from listvenite-birbirite seafloor alteration and leaching of ultramafic rocks. Additionally, they address for the first time the contribution of critical elements such as Bi, Pb, Sn, Mo, and Ga by crustal metamorphic fluids during orogeny in the well-studied Outokumpu deposit.